Integrated approach to traceability data management

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Abstract. Globalization of trade and higher volume flows lead to the necessity of new approaches in design of traceability systems. Since containerization becomes a dominant technique in the general cargo trade and RFID (Radio Frequency Identification) technology have already proven to be effective in traceability systems to get data about physical objects, this paper proposes an integrated approach to RFID data management within traceability system for containers. At first, it is proposed to apply peer-to-peer distributed network for data accumulation as the most natural approach to manage a plenty of widely spaced objects that are able to communicate with each other. Then the general idea of ontological approach to store and organize traceability data is expressed in order to enable integration among systems and data through semantic interoperability. Finally, it is proposed to analyze traceability data according to business processes of related organization for detection of any deviations in a process chain.

Key words: Business Process Model, Multi-agent, Ontology, peer-to-peer, RFID, traceability

1 Introduction

Traceability refers to the completeness of the information about every step in a process chain. It refers to the capability of an application to track and trace the state of objects, discover information regarding its past states and potentially estimate future states. Traceability is essential to a wide range of applications such as manufacturing control (identification and tracking of people, equipment, parts, goods, etc.), procurement, operations maintenance, inventory, logistics of distribution, product recalls, and anti-counterfeiting [1] [2].

This research concentrates on three aspects of traceability: getting on-line data from traceable objects, storing data and data analysis. RFID (Radio Frequency Identification) technology has already proven to be effective in traceability systems to get data about physical objects [3], but methods of gathering data and transferring it to an application for further analysis give a fertile field for research [4]. Another problem of traceability is to store comprehensive set of data about traceable objects. It is supposed that stored data must be scalable and universally organized in order to be suitable for future changes and applicable for analysis by different applications. In addition, even methods of traceability data analysis vary from human processing to complex enterprise resource planning (ERP) applications, exploration of new analytical methods of data processing could effectively respond needs of traceability systems. To address these challenges we propose some key concepts for creation of efficient traceability system that is based on RFID infrastructure.

The first idea is to apply peer-to-peer (P2P) distributed network for data accumulation as the most natural approach to manage a great deal of widely spaced objects that are able to communicate with each other. A request for information from a large network can potentially be delayed in case of managing and transferring the information via one central server (centralized solution). Otherwise, distributed information repository together with the ability of network nodes to communicate with each other helps to avoid transmission bottlenecks even distributed approach comes with other problems. Thus, the part of our research is aimed on proper traceability data collection across P2P network along with the possibility of on-line data extraction for analysis.

The second idea is to organize stored data according with ontological knowledge about tracking and tracing objects. Ontological approach leads to creating complete data storage. And even more, proper ontological model allows organize data in a universal way to enable integration among systems and data through semantic interoperability. It is suggested to use the ISO 15926 standard [5] for ontology creation as a standard issued for data integration, sharing and exchange between computer systems. Since it was suggested to use RFID technology for tracing objects, proposed ontology must be also built as to include the templates of specified RFID data [6], as well as all future invented templates of additional and RFID data. The idea of ontology creation for RFID data is not new on its own, but this research is aimed to supplement RFID data concepts in the ISO 15926 POSC Caesar RDL (Reference Data Library) [5] by new knowledge from port freight traffic activities as well as to present the way of ontological data usage in a traceability system.

The third idea is to define any deviations of process chains from projected traffic activities by comparing real-time and historical data from P2P network with data quantifications and customer requirements come from guidelines and procedures of related organizations. In our research we explore *an automated extraction* of business rules and data requirements from business process models of organizations, as well as *automated comparison* of extracted and “real” data. DEMO[1] (Design and Engineering Methodology for Organizations) [7] methodology was chosen for the description of business operations in and between organizations involved in process chains. This methodology has already proven to be effective in extraction of the essence of an organization and presenting this information at the ontological level of abstraction, which makes DEMO methodology the most suitable for automated data processing.

[1] http://www.demo.nl/

The remainder of the paper is organized as follows. First, the necessity of new approach in architecture of traceability systems is proved in section 2. Then some theoretical background about RFID technology, ISO 15926 standard and DEMO is outlined in section 3. Proposed architecture of integration RFID software and enterprise applications is described in section 4. Finally, section 5 provides the directions for further research.

2 Field of Application

Despite declines in 2008-2009, steady growth in freight volumes occurred over the past fifteen years [8, 9]. This trend is very likely to continue in future that leads to increasing demand for intermodal capacity and exploration of new approaches in supply chain management. As long as traceability can be considered as indispensable part of applications in the field of "supply chain visibility", our research aims at developing of new traceability system architecture that is based on relevant standards, technologies and principles.

Proposed architecture will be applied for shipping operations of two largest ports in Haute-Normandy, France – Le Havre and Rouen. Port authorities generally are well aware of the fact that they need to enhance the development of fast, efficient, reliable and sustainable intermodal transport network [8], however 1) the direct financial involvement of European port authorities is limited to investments and maintenance of port infrastructure that is dominated by public authorities; 2) the transport level is dominated by transport operators, who under normal circumstances do not have to give account to the port authority. Thus nowadays port authorities act as catalysts in the development of information systems at the logistical level.

In the 1950s revolutionized concepts of containerization and intermodality emanated from a growing demand for goods accessibility. Initially these concepts influenced port organizations and, at a later stage, inland transportation. Nowadays containerization becomes a dominant technique in the general cargo trade. Thus total container traffic in Europe increased from 4.3 million TEU (Twenty feet equivalent unit) in 1975 to 24.7 million TEU in 1996, and then to 95 million TEU in 2010, when the worldwide container traffic reached a total of 560 million TEU [8, 10].

With the assumption that containerization will continue to grow, proposed traceability system is intended to be able to work with information about containers. Also the application should be integrated with the RFID solutions as RFID is going to play a key role in automated universal identification systems for tracking, accessing and securing assets, products, personal, equipment throughout in the supply chain.

Although maritime technologies and the physical layout of modern container terminals in theory allow a fast transfer from seagoing vessel to inland transport mode, it can be observed that it usually takes several days before the container eventually heads for the hinterland [10]. Containers are often delayed in a terminal just awaiting instructions for further dispatch. Neither properly collected and accessible data from a distributed network nor complex analysis techniques or transparent business processes model in a port will not solve the problem on its own. That is why an intermediate level of the application is required. On this level 1) information about containers should be analyzed according with port capabilities and rules; 2) optimal solution for further cargo deliveries should be generated by the application in order to reduce the need for human intervention.

3 Theoretical Background

3.1 RFID technology

Radio Frequency Identification (RFID) technology was first used in World War II for objects identification. Nowadays RFID is part of a wide range of technical solutions [6]. In its simplest form an RFID system consists of transponders (*tags*) attached to objects (e.g. containers), and interrogators (*readers*) that interpret radio waves from tags into digital information and communicate with other readers to determine positioning.

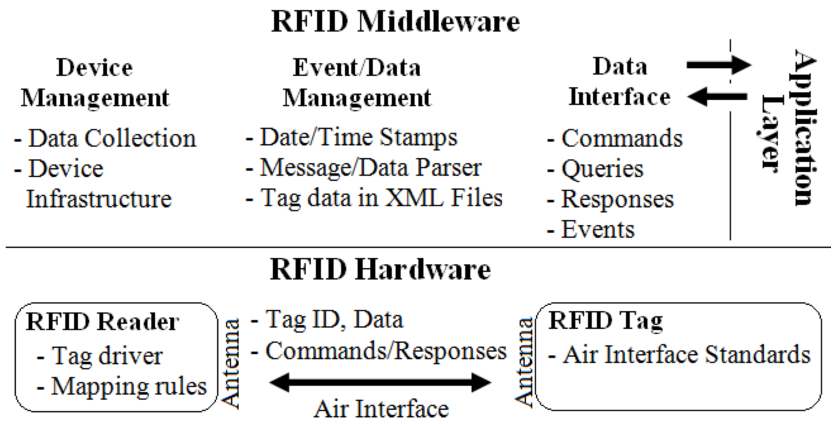

Fig. 1. Architecture of RFID hardware and software.

Every RFID tag has a unique identification number (ID)[2] and additionally it can keep some information in a rewritable memory. All information from tags is transmitted to readers, and then stored on host controllers. Host controllers may be implemented as host computers, intelligent readers or a central server. It is assumed that host controllers are equipped with RFID middleware that serves two main functions. First, middleware is responsible for providing management and monitoring functionality, ensuring that the readers are connected, functioning properly, and correctly configured. Secondly, middleware receive, collect, filter, and aggregate data from readers, and communicate with upper-level applications (Fig. 1).

[2] A traceability system may use the ID of the tag to identify containers in the same way as in a barcode system [4].

3.2 Data modeling

RFID data needs to be made available for various upper-layer applications. A first step towards integration of data is its standardization. Information to be exchanged should be represented in a logical structured language that is application independent. This idea was supported in 2007 by some large-scale energy companies [11] which financed a project outlining the deployment of RFID technology in the offshore oil and gas industry. They encouraged the development of RFID data ontology according with meta-data model defined in the ISO 15926 "Integration of lifecycle data for process plants including oil and gas production facilities" [5] standard as the only available ISO standard for data integration across time, disciplines and functional domains [12].

The ISO 15926 consists of some parts, including 1) the data model that determines the syntax used to define the semantics (terminologies, taxonomies and ontologies); 2) template methodology as implementation methods for the integration of distributed system; 3) technologies for knowledge representation; 4) the core reference data, which holds the semantic for key concepts [12].

The data model and the initial reference data from the ISO 15926 can be used as a basic reference classification for defining terms in databases and data warehouses. Standardized reference data is maintained and enhanced by Special Interest Groups within POSC Caesar Association (PCA). The data is accessible in PCA Reference Data System (RDS) on PCA's web site (http://www.posccaesar.org). Currently this repository contains only partially developed RFID concepts that must be extended by new ones in order to build complete traceability data model.

3.3 DEMO methodology

DEMO is a methodology for the design, engineering, and implementation of organizations [7]. DEMO provides the theory to build enterprise ontology: the essence of an organization, fully independent from its implementation. The methodology has been developing since 1980s by Jean Leonardus Gerardus (Jan) Dietz, Professor Emeritus of Information System Design at Delft University of Technology. Trough numerous successful practical DEMO-projects, the methodology acquired a reputation as a complete and objective operation description of an organization. Thus nowadays it is advanced and disseminated by the Enterprise Engineering Institute[3].

In contrast to different notations which are commonly used to build organizational model like IRIS, IDEF, UML, etc., DEMO methodology describes construction and operation of social organization by an *ontological* model that is essential and complete on conceptual level, logical and free from contradictions, compact and succinct, independent of its realization and implementation issues.

According to DEMO, conceptual model of the enterprise is based on PSI (ψ) theory (Performance in Social Interaction) that consists of four axioms and one theorem:

[3] http://www.demo.nl/

- The *Operation Axiom* states that people in an organization are *actors* which can play different *actor roles* and perform two kinds of acts: *production acts* and *coordination acts*. By performing *production acts* the actors contribute to bringing about the goods and/or services that are delivered to the environment of the enterprise [7] (e.g. storage, transportation, judgment, making a decision or appointment, etc.). By performing *coordination acts* actors enter into and comply with commitments towards each other regarding the performance of production acts [7].
- The *Transaction Axiom* states that production and coordination acts are performed as steps of universal patterns, called *transactions*. Each transaction is carried out by two actors (*initiator* and *executor*) and consists of *order* conversation and *result* conversation about execution of production act as well as *execution* phase itself.
- The *Composition Axiom* states that a business process is a collection of causally related transaction types [7], such that each transaction is initiated either by a request performed by an actor role in the environment (*external activation*) or a request by an internal actor role to itself (self-activation).
- The *Distinction Axiom* states that there are three distinct human *abilities* playing a role in the operation of actors, called *performa*, *informa* and *forma* [7]. The *forma* ability regards data handling without its context or meaning; *informa* ability designates intellectual capacity of actors; and *performa* ability concerns the ability of actors to produce originally new things.
- *Organization theorem* states that the organization of an enterprise is the layered integration of three homogeneous systems: the B-organization (from Business), the I-organization (from Intellect), and the D-organization (from Document). All three aspect systems are in the category of social systems, they differ only in the kind of production: the production in the B-organization is ontological, the production in the I-organization is infological, and the production in the D-organization is datalogical [7].

DEMO methodology builds a detailed view on interaction and management processes of an enterprise from four aspect models:

- The Construction Model (CM), composed of Interaction Model (IAM) and Interstriction Model (ISM), reveals the ontological construction of organization via *transaction kinds* and associated *actor roles* linked with *information banks*.
- The Process Model (PM) relates each transaction type of the CM to the generic transaction pattern. Besides it shows how the distinct transactions are interrelated.
- The Action Model (AM) determines the imperatively formulated business rules that serve as guidelines for the actors in dealing with their agenda. It contains one or more action rules for each agendum type [13].
- The State Model (SM) specifies all object classes, fact types, transaction result types, and the ontological coexistence rules that are contained in the AM [7].

4 Application Structure

From authors' prospective common architecture of traceability systems [12] can be enhanced by three components which provide proper distribution and analysis of RFID data: P2P network to exchange and quickly retrieve data, Analytic module for intelligent data analysis, and Ontology as a basis for complete data model (Fig. 2).

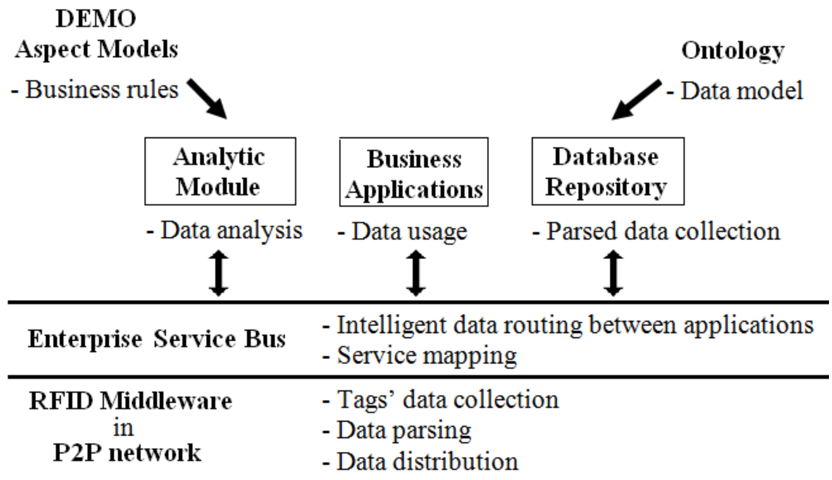

Fig. 2. Proposed traceability system architecture

Besides it is assumed that existing standards are strictly followed at all levels of traceability system. Thus the ISO/IEC 15962 standard should be used for data processing and presentation to/from RF tags. In addition, semantic part of RFID data, which is transferred between P2P network and the application layer, should be built according with the ISO/IEC 15961.

Here after details and benefits of main components of proposed traceability system are specified.

4.1 Agent-Based Solution for Middleware Layer

Analysis of different RFID middleware solutions [12][14] revealed that centralized approach is still dominated among them. That is why in this paper it is proposed to build traceable P2P network from the following types of host computers (called 'peers' or 'nodes'): Decision-Maker, Regular Node and Super Node. Decision-Makers provide an interface for users of traceability system and are able to analyze tracing information. Regular Nodes are linked with RFID readers and accumulate information about tracing objects placed within specified location. Super Nodes manage communication process in P2P network.

It is supposed that Regular Nodes and Super Nodes form a group if they are related to the same enterprise. Since organization can facilitate the interconnection between concomitant peers in a group, all peers in one group are able to communicate with each other and work together to provide a service when it cannot be provided by an individual host computer. Regular Nodes from the same group are isolated from other groups, whereas Super Nodes are imposed to communicate with Decision-Makers as well as with Super Nodes of other groups.

From authors' perspective traceability middleware that is placed on host computers, can be built as a multi-agent application. Types of programming agents should correspond to types of host computers and the identificator of each agent should consist of two parts: internal identificator in a group and the name of the group. Peers, presented by intellectual agents, use this form of identificator to identify themselves to the Internet [15].

The main challenge here is to build multi-agent model of P2P network that would be the most applicable for nodes communication in and between spread locations. Even P2P systems have already become a popular medium to share huge amounts of data [16][17], there are, however, many open problems that must be overcome before a real P2P network can be effectively deployed in port areas. That is why it was proposed first to build a virtual P2P network based on JXTA technology (programming language and platform independent Open Source protocol for peer-to-peer networking) [15] in order to simulate the most suitable platform for the whole traceability system.

4.2 Data Model of Proposed Traceability Application

XML representation of RFID data can be based on different models. In its simplest form XML tags correspond to the attributes which are ordered in Database tables. However, these attributes are usually different in databases owned by various organizations. In this paper it is proposed to use the meta-data model from ISO 15926 as *unified* classification for defining terms in database of traceability system. Due to historical reasons, basic classification of referenced entities of RFID data have been built by POSC Caesar Association according with ISO 15926 and NORSOK standard Z-015 [18]. Moreover, PCA association supports data federation, so that different organizations and communities can choose their own needs for industrial standardization. At the first phase of this research basic RFID data model from PCA RDL library [5] was analyzed.

Besides, ontologies are known to be well suited for an evolutionary approach to the specification of requirements and domain knowledge [19]. That is why in the scope of our research we will continuously supplement PCA Reference Data System (RDS) with new definitions of tracing data and activities derived from RFID specifications and port documentation without damaging of data storage that is built according to the data model defined in the ontology.

In addition, automated validation and consistency checking are considered as a potential benefit of using ontology for discovering of new tracing data and freight activities [19].

4.3 Business Process Integration

Proposed application for tracing data analysis is called Analytical Module. This module is aimed to define any distortion of process chains from projected traffic activities by comparing traceability data from P2P network with pre-defined data quantifications that come from documented requirements of concerned organizations. Functioning of this part of proposed traceability system can be considered on two levels: business and information.

At the information level automated validation and consistency checking of RFID data are performed by the Analytical Module. As soon as a new request to analyze RFID data comes to the system from the user or other Enterprise Application, related tracing information is extracted from P2P network to the Analytical Module. Then coming RFID data is analyzed according to pre-defined data model.

Except of a real data from tracing objects, the Analytical Module contains information about business processes. It is assumed that this module is able to perform an intelligent analysis of tracing data by mapping this information to related business processes of organizations that are concerned. Though usually this function of traceability system is related to human activities and cannot be totally replaced by operations of the Analytical Module, some part of intelligent data analysis can be passed to the business level of the Analytical Module.

DEMO model of organization was chosen as the one that provides complete organization ontology and is perfectly understandable on business level, and on the other side, as the very suitable ontological organization model for extraction of complete set of business rules. Thus it is supposed the Analytic Module can derive freight operations from corresponding decision rules of the Action Model, and keep them in XML format. Moreover, the Fact Model can be considered as a resource of supplementary information for RFID data analysis.

Even some research have been already done in this area [13][20], at the moment there is no algorithm for conversion of four related aspect models to the format that can be read easily on the application level of traceability system. In the scope of our research it is planned 1) to develop a method for automatic extraction of business rules from any DEMO model of organization, as well as 2) to implement an algorithm of comparing tracing data from P2P network with business rules of related organization.

5 Conclusions

In this paper we proposed a new approach to design of integrated traceability systems aimed for tracing data accumulation and analysis. In the scope of offered approach we enhance basic components of common solutions. At first, agent-based model was suggested for data aggregation in a distributed infrastructure. Then the new method of data analysis was proposed based on multi-agent representation of concepts of enterprise engineering methodology.

Moreover, as a result of ontological approach to data modeling and analysis it is implied that offered solution of traceability problem can be implemented extensively and independent on the field of application. It is assumed that implementation of proposed model of traceability system will reduce the necessity of manual control in supply chain operations and will be able to generate a quick solution in response to random changes in the environment related to tracing objects.

In the nearest future designed components of traceability system will be implemented on multi-agent platforms.

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